DESIGN, FABRICATE AND TESTING SMALL ROCKET MOTOR

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ABSTRACT

There was a lot of study on Solid Rocket Motor (SRM) based solid propellant. This project focus on and discusses the study of optimum design based SRM characteristics including the methods of the optimum design selection and fabrication, analysis using COSMOS and static thrust testing. Before that, the researcher has focus on the fundamental of solid rocket motor for designing and fabricating. There are two main factors need to be considered in the design selection and fabrication which are performance or processability and mechanical strength. The theoretical performance of the propellant was obtained by using CHEM program. Together with literature study and theoretical performance, three models or design of nozzle with different size throat were finalized with consideration of the mechanical and processability factors. The propellant was a mixture of Potassium nitrate and sucrose. The rocket motors were manufactured or fabricated using lathe and milling machine. Then three solid rocket motors were tested to get the thrust and performance. The results show that the increasing of thrust and combustion pressure lead to the decreasing the throat size and increasing the throat length. The highest thrust was 1260N and burning time about 4 Sec. Meanwhile, for the performance characteristics, the specific impulse, I_{sp} that obtained from static thrust testing for solid propellant was 4% lower than theoretically.

ABSTRAK

Terdapat banyak kajian mengenai Roket Enjin berdasarkan bahan bakar pepejal. Keutamaan projek ini untuk membincangkan serta membuat kajian mengenai cirri-ciri reka bentuk terbaik ataupun optimum yang berasaskan SRM termasuk pemilihan reka bentuk terbaik dan analisis menggunakan COSMOS sebelum proses pembuatan roket enjin dilakukan. Sebelum itu penyelidik telah member tumpuan kepada asas-asas pembinaan enjin roket. Terdapat dua factor yang harus diambil kira semasa proses pemilihan bahan untuk membina enjin roket ini iaitu kekuatan bahan dan daya ketahanan bahan dalam tekanan dan suhu yang tinggi. Daya tujah pada awalnya diambil kira setelah menggunakan CHEM. Secara teorinya kita telah mendapat hasil daya tujah roket tersebut dan dapat membuat kesimpulan awal untuk pemilihan reka bentuk yang terbaik. Perubahan luas tekak roket enjin dapat mengeluarkan hasil yang berbeza-beza dan adakalanya gagal disebabkan saiz tekak tidak sesuai dengan tekanan yang dikenakan. Tiga enjin telah diuji untuk dilihat serta dicatat hasilnya untuk dibuat kesimpulan dan pemilihan yang paling terbaik. Bahan bakar yang digunakan dalam projek ini adaqlah Pottasium Nitrat dan sukrosa. Hasil kajian menunjukkan bahawa peningkatan tekanan teras dan pembakaran membawa kepada panjang tekak. Daya tujah yang tertinggi yang Berjaya dihasilkan adalah 1260 newton dan terbakar dalam kira-kira 4 saat. Bahan bakar yang digunakan dalam projek inin adalah bahan bakar untuk pembuat roket amatur.

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LIST OF SYMBOLS

α	alpha ferrite
°C	Degree Celsius
%	Percentage
λ	correction factor
L_{cone}	length of cone
r_2	outer radius
$\dot{m}$	mass flow rate
P_c	Pressure chamber
A_t	Throat area
T_c	Chamber temperature
R	Ryberg constant
A_e	Exit area
P_e	Exit pressure
k	Gamma
V_t	volume of throat
mm	millimeter
m	Meter
$\in$	throat ratio
m/s	Meter per second
$P_\circ$	Initial pressure
R_p	Resistant potential
s	second
M	Mach number
v_t	volume of throat
T_t	temperature of throat
γ	Gamma ferrite

ρ	density
F	thrust
C_F	thrust coefficient
I_s	specific impulse
c^*	cee-star
g_o	gravity
a	speed of sound
γ	specific heat ratio

LIST OF ABBREVIATIONS

A	Area
AISI	American Iron and Steel Institute
C	Carbon
d	Density
KNO_3	Potassium nitrate
Fe^{2+}	Iron ion
Fe_3C	Cementite
H_2O	Water
L	Liquid
M	Metal
Mn	Manganese
m/s	metre per second
NaCl	Sodium Chloride
O_2	Oxygen gas
OH	Hydroxide
CHEM	Chemical
S	Sulphur
FKM	Faculty of Mechanical Engineering
FYP	Final Year Project
UMP	Universiti Malaysia Pahang

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rocket motor is one of the significant components in constructing amateur solid rocket and it comprises a lot of application theory of the nozzle. This component of nozzle and fluid flow related to the pressure, temperature and velocity. The prior knowledge about rocket motors' theory and nozzle must be studied in order to get the blue prints for the design. Another vital thing that needs to be considered while creating this rocket motor is, it must be design for optimum dimension and need to be analysed by using COSMOS or Fenite Element Analysis. An Optimum dimension can be defined as the best diameter of the nozzle, because in theoretical knowledge, there is a rule about exit diameter and throat diameter for nozzle. Besides that, for preventing any failure during test launcher, suitable angle also must be considered in this project because incorrect dimension for rocket motors will lead to failure during launcher. So, crucial things in getting the best result for analysis will depend on the correct dimension and angle design. Next, fabricate the rocket motors and test rig where the rocket motors was fabricated by using lathe machine and drilling machine. Finally, report writing with the real result of testing.

1.2 Problem Statement

This project is about our idea of designing the optimum rockets motor for a small launcher and conducting an analysis in the rocket motors. The rocket motor in this project functioned as a device producing thrust in rocket's launching. In the rocket's industry, the rocket engine usually built by using the theory of nozzle and fluid low where its design and structure become the key point in creating a good rocket engine. The correct design and size of rocket engine must be created in order to support rocket during launching and any failure will bring danger to the people in the rocket if the rocket explode.

1.3 Project Objectives

Developing an optimum performance for rocket motors by two primary objectives first to theoretically analyze the operation of small solid propellant rocket motor and to conduct testing with which to compare the theoretical result.

1.4 Scope

i. Design of a rocket motors (including the COSMOS's analysis)
ii. Fabricate the rocket motors
iii. Conduct experimental and test rig
iv. Analysis and report writing

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Solid motor rocket consists of nozzle, casing, propellant and igniter same as in figure 2.1. But it also comprises time delay and the charger which process the explosion of parachute. Generally, the rocket could be propelled by using liquid or solid propellant. In this study, only solid propellant for rocket motor will be discussed. The main elements for solid propellant are oxidizer, fuel and binder.

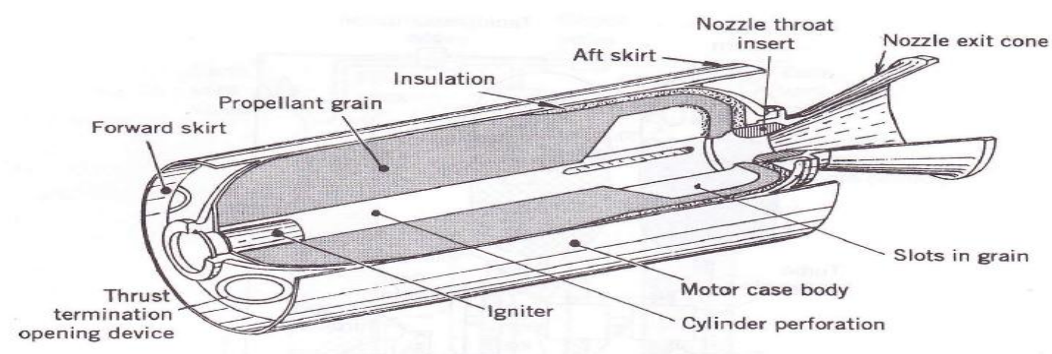

Figure 2.1: Solid Rocket Propellant

- Source : Refferences Book (P.R EVANS "Composite Motor Case Design")

Solid rocket motor consists of a solid propellant grain embedded into a stronger metallic or composite case with an insulator material and a liner between the case and the grain. The motors which are mainly utilized in defense and space technologies are generally for a long time and transported from one place to another before their ignition process. Mechanical properties of solid propellant are very sensitive to temperature changes. (H.C Yildrim, 2010)

2.2 Nozzle theory

A nozzle is a device design to control the pressure or characteristic of a fluid flow especially to increase velocity as it exists or enters an enclosed chamber or pipe by an orifice. A nozzle is often a pipe or tube of varying cross sectional area, and it can be used to direct or modify the flow of a fluid liquid or gas. Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and the pressure of the stream that emerges from them. Increase the kinetic energy of the following medium at the expense of its pressure and internal energy. Nozzle typically involves no work and any change potential energy is negligible. But nozzle it experiences large changes in its velocity. The principal conservation of mass in a steady flow with a single inlet and outlet is expressed by equating the mass flow rate $\dot{m}$.

2.3 Type of nozzle & Correction Factor

The nozzle is a device that increases the velocity of a fluid at the expense of pressure. The cross sectional area of the nozzle decreases in the flow direction for subsonic flow and an increase in supersonic flow. The rate of heat transfer of fluid that flowing through a nozzle by the surroundings is very small since the fluid has high velocities, and thus it does not spend enough time in the device for any significant heat transfer to take place. In rocket applications, nozzle can be divided into two types which are conical and bell nozzle. Bell’s nozzle more efficiency than conical nozzle but for our design or amateur design, we consider the conical nozzle because it easier to fabricate compared to the bell nozzle.

2.4 Cone and Bell Shape Nozzle

The conical nozzle is the oldest and perhaps the simplest configuration. It is relatively easy to fabricate and still be used today in the many small nozzles. A theoretical correction factor λ can be applied to the nozzle exit momentum of an ideal rocket with a conical nozzle exhaust. This factor is the ratio between the momentum of the gases in a nozzle with a finite nozzle angle 2α and the momentum of an ideal nozzle with all gases flowing in an axial direction :

$$\lambda = \frac{1}{2}(1+\cos\alpha) \tag{2.1}$$

Where :

λ = Correction factor
α = cone divergence half angle

For a rocket nozzle with a divergence cone angle of 30° (half angle = 15°) the exit momentum and therefore, the exhaust velocity will be 98.3% of the velocity calculated. A small nozzle divergence angle causes most of the momentum to be axial and thus gives a high specific impulse, but long nozzle has a penalty in the rocket propulsion system mass. A large divergence angle gives short and light weight design but performance is low. Below figure shown the optimum conical nozzle shape and length (between 12° and 18°) :

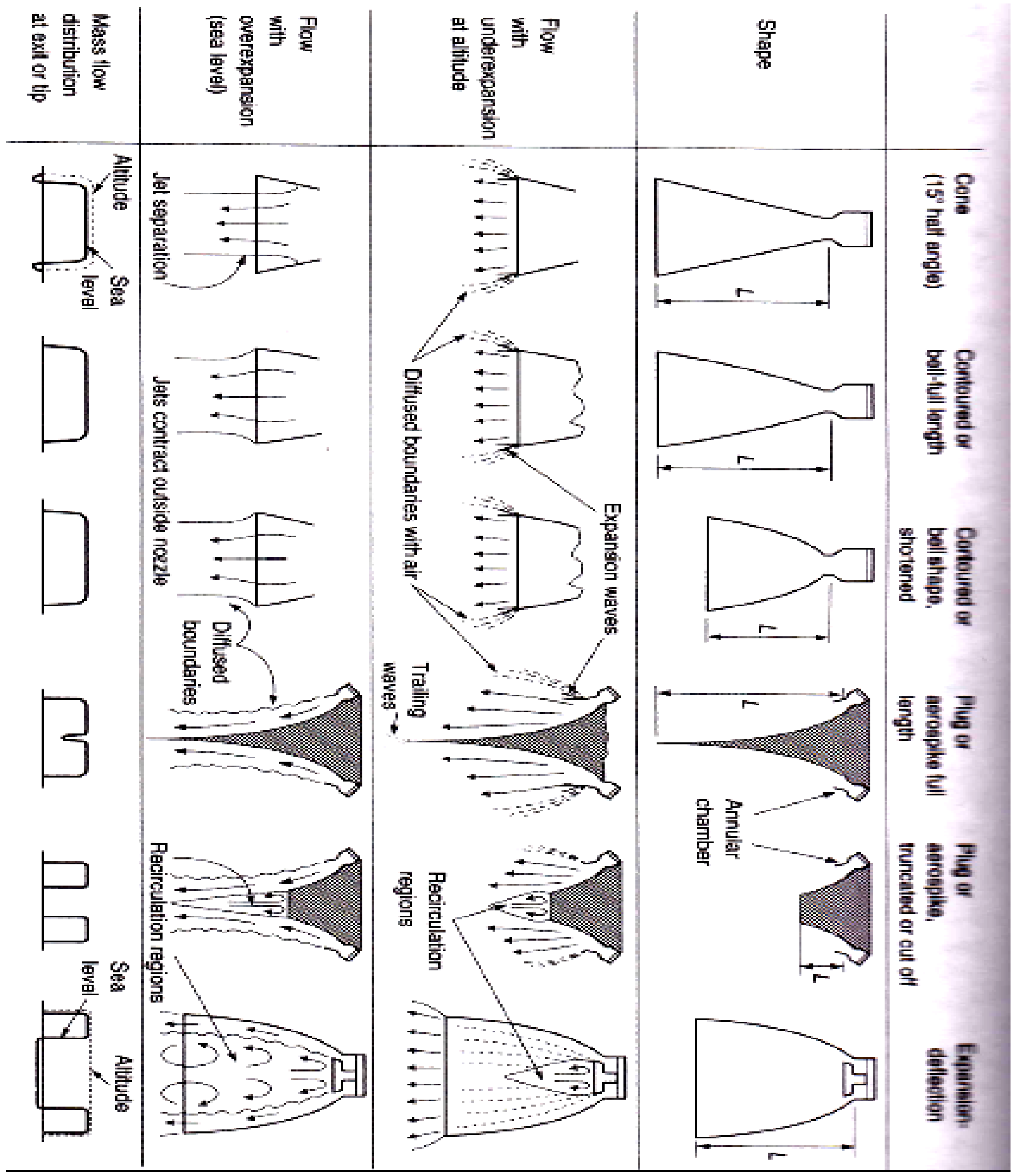

Figure 2.2 : Simplified diagram of several different nozzle configurations and their flow effect

Table 2.1 : Correction factor

Nozzle Cone Divergence Half Angle (degree)	Correction factor
0	1.0
2	0.9997
4	0.9988
6	0.9972
8	0.9951
10	0.9924
12	0.9890
14	0.9851
15	0.9830
16	0.9806
18	0.9755
20	0.9698
22	0.9636
24	0.9567

A change flow direction of a supersonic gas in an expanding wall geometry can only be achieved through expansion waves. Related formula for ratio length expansion nozzles with radius:

$$L_{cone} = \frac{r_2 - r_1}{\tan\alpha} \tag{2.2}$$

Where :

L_{cone} = Divergent length
r_1 = Throat radius
r_2 = Exit radius
$\tan\alpha$ = Cone divergence half angle

The theory has previously said there are differences in the fluid flowing through the nozzle. The properties of the fluid can be expressed in the figure below.

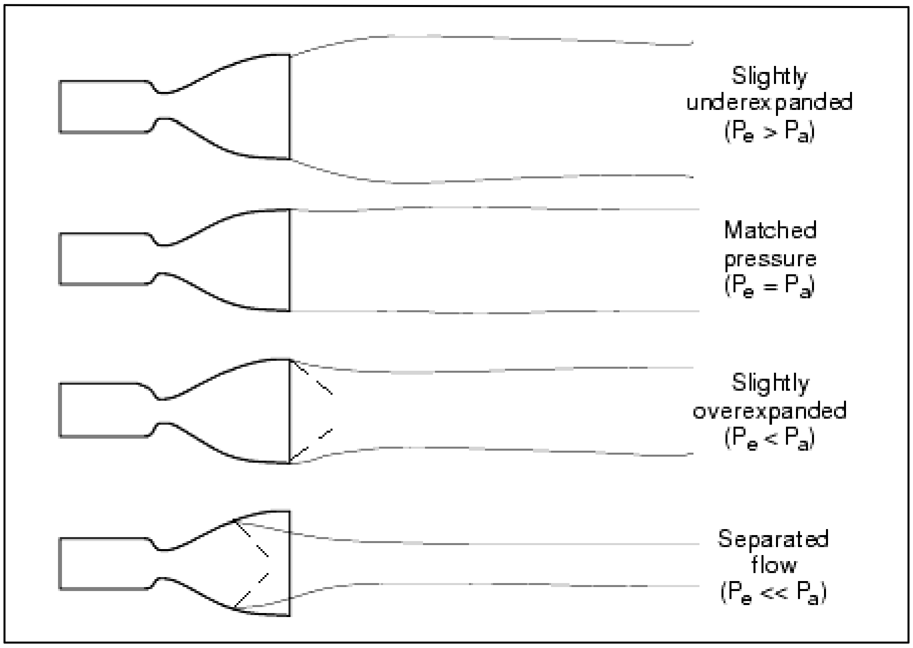

Figure 2.3 : Type Of Flow

- Source : Refferences Book(Rocket Propulsion Elements (Eighth Edition) by George P.Sutton & Oscar Biblarz)

2.5 Supersonic nozzle

For a rocket motor, the nozzle usually has a circular cross section. The combustion chamber radius R_c is obtained from the study of the chamber while the value for the throat area A_t and throat radius R_t is from equation:

$$\dot{m} = \frac{rP_cA_t}{(RT_c)^{\frac{1}{2}}} \tag{2.3}$$

Where :

$\dot{m}$ = Mass flow rate
T_c = Chamber temperature
P_c = Chamber pressure
A_t = Throat area

Finally the radius and area of the nozzle exit is obtained from the equation:

$$\frac{A_e}{A_t} = \frac{r}{\left(\frac{P_e}{P_c}\right)^{1/k} \left[\frac{2k}{(k-1)} \cdot \left\{1-(P_e/P_c)^{(k-1)/k}\right\}\right]} \tag{2.4}$$

Where :

k = Specific heat ratio
T_c = Chamber temperature
P_c = Chamber pressure
A_t = Throat area

In actual the nozzle performance is not very sensitive to the geometric design which is selected for easy manufacturing. For a convergence conical half angle is around 30 degrees. The radius of curvature near the throat must be sufficient enough in order to ensure the progressive velocity increase. Finally, area increase in the divergence must be sufficiently progressive avoid boundary layer separation.

Supersonic nozzle the ratio between the throat and any downstream area at which a pressure prevails can be expressed as a function of the pressure ratio and the ratio of specific heats by using the equation below :

$$V_t = \sqrt{\frac{2k}{k+1} R T_1} \tag{2.5}$$

Where :

k = Specific heat ratio
T_c = Chamber temperature
V_t = Throat velocity

As we know, the function of the nozzle is converting the thermal energy in the propellant into kinetic energy as efficiently as possible, in order to obtain high exhaust velocity along the desired direction. The required nozzle area decreases to a minimum and then increases again. It consists of a convergent section followed by divergent section.

Throat pressure for isentropic flow called critical pressure ratio range between 0.53 and 0.57 of the inlet pressure. Flow for the inlet condition less than the maximum if the pressure ratio longer than that given. The equation of the critical pressure and throat pressure ratio at below:

$$\frac{P_t}{P_c} = \left[\frac{2}{(k+1)}\right]^{k/(k-1)} \tag{2.6}$$

Where :

k = Specific heat ratio
P_c = Chamber pressure
P_t = Throat pressure

$$P_{\circ} = P\left[1 + 1/2(k-1)M^2\right]^{k/(k-1)} \tag{2.7}$$

Where :

k = Specific heat ratio
$P_{\circ}$ = Critical pressure
P = Atmosphere pressure
M = Mach number

Besides that, at point critical pressure the values of the specific volume, temperature and velocity can be obtained :

$$v_t = v_c \left[\frac{(k+1)}{2} \right]^{1/(k-1)} \tag{2.8}$$

$$T_t = \frac{2T_c}{(k+1)} \tag{2.9}$$

$$V_t = \sqrt{\frac{2k}{k+1} R T_c} \tag{2.10}$$

Where :

k = Specific heat ratio
T_c = Chamber temperature
V_t = Throat velocity
v_t = Volume throat
v_c = Chamber volume

2.6 Nozzle flow and throat condition

Nozzle of this type consists of the convergent section followed by divergent section. From the continuity equation, the area is inversely proportional to the ratio velocity per volume. This quantity has been plotted in Figure 2.7. There is a maximum in the curve because at first the velocity increases at a finer than the precise volume. However, in divergent section the exact volume increased at a finer rate. The minimum nozzle area is called the throat area. The ratio of the nozzle exit area to the nozzle throat area is called the nozzle expansion area ratio. It is an important nozzle parameter:

$$\in = \frac{A_e}{A_t} \tag{2.11}$$

Where :

$\in$ = Expansion area ratio